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THE ORIGIN OF KNO SCALING VIOLATION IN THE PARTON BRANCHING MODEL

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ABSTRACT

We present multiplicity distributions in the parton branching model.[1)] We obtain a new non-scaling low for the probability distribution.[2)] In the high energy limit, when we neglect quark evolution, scaling is approached from below in agreement with experimental data.

1. INTRODUCTION

In 1972 Koba, Nielsen and Olesen[3)] predicted, that at sufficiently high energies

$$\bar{n} \frac{\sigma_n}{\Sigma\sigma_n} = \psi(z = \frac{n}{\bar{n}}) \tag{1}$$

where σ_n is the partial cross section for producing a state of multiplicity $\bar{n}$ and $\psi(z)$ is energy independent function. For $p\bar{p}$ collisions this scaling seemed to hold approximately for energies up to ISR,[4)] but at CERN collider[5)] energies scaling violations have been observed. On Fig. 1 we see that KNO scaling violations are manifested in rising and broadening of the multiplicity distributions suggesting that if there is any scaling, it is approached from below as energy increases. The parton branching model that we derive in the next section systematically deviate from KNO scaling by approaching the scaling from below in the high z tail in agreement with the experimental data.

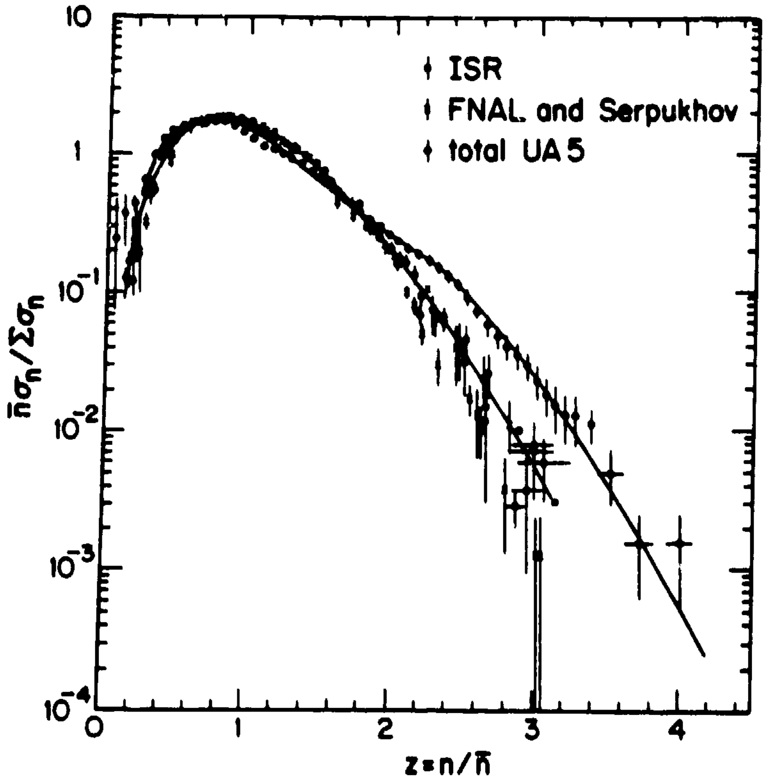

Fig. 1. The multiplicity distributions $\bar{n}\sigma_n/\Sigma\sigma_n$ plotted as a function of $z = n/\bar{n}$, for energy ranges from FNAL (s~10 GeV) through ISR (s~63 GeV) to CERN Sp$\bar{p}$S collider (s~540 GeV), Ref. 3.

2. MODEL BASED ON QCD BRANCHING PROCESSES[1]

a) <u>The coupled quark-gluon equations</u>. We assume that hadrons collide producing n_o initial gluons and m_o initial quarks with the corresponding probability distribution $P_{mn}(n_o,m_o,t)$. These gluons and quarks branch loosing their energy. When they reach the hadronization energy, branching stops and quarks and gluons hadronize. Scaling violations can come from any of these stages. In this paper we assume that number of partons is proportional to the number of hadrons and we concentrate on the branching stage. We consider the following branching processes: quark bremsstralung, 3-gluon branching, $q\bar{q}$ pair production and 4-gluon branching with probabilities $\tilde{A}$, A, B, and C respectively.[6]

The probability distribution for getting m quarks and n gluons satisfies the following evolution equation

$$\frac{\partial P_{mn}}{\partial t} = -AnP_{mn} - BnP_{mn} - \tilde{A}mP_{mn} - CnP_{mn} + A(n-1)P_{m\ n-1}$$

$$+ \tilde{A}mP_{m\ n-1} + B(n+1)P_{m-2\ n+1} + C(n-2)P_{m\ n-2} \quad . \tag{2}$$

where t is the evolution parameter related to the parton energy, $t \sim \ln\ln Q^2$. This equation can be solved exactly only in some limiting cases. If we assume that P_{mn} is a smooth function of m and n and $nP_{mn}(mP_{mn})$ varies slowly between n and n+1 (m and m+1) Eq. (2) becomes a differential equation for the probability distribution P(m,n,t):

$$\frac{\partial P(m,n)}{\partial t} = \cdot [A+2C-B]P(m,n) + [-(A+2C-B)n-\tilde{A}m] \frac{\partial P(m,n)}{\partial t} - \tag{3}$$

$$- 2Bn \frac{\partial P(m,n)}{\partial m} + \cdots$$

where we have neglected terms higher than second order in the Taylor expansions. Eq. (3) can be solved with the assumption of n_o initial gluons and m_o quarks. In that case we obtain a new non-scaling law for the probability distribution P(m,n):

$$(m - \frac{2B}{\lambda^+}\bar{n})\ (\bar{n} + \frac{\tilde{A}}{\lambda^+}\bar{m})\ P(m,n) = \psi \left(\frac{m - \frac{2B}{\lambda^+}n}{\bar{m} - \frac{2B}{\lambda^+}\bar{n}}\ ,\ \frac{n + \frac{\tilde{A}}{\lambda^+}m}{\bar{n} + \frac{A}{\lambda^+}\bar{m}} \right) \tag{4}$$

where

$$a_o = A - B + 2C,\ \lambda^{\pm} = \frac{a_o}{2}\ (1 \pm \sqrt{1+8\tilde{A}B/a_o{}^2}) \quad . \tag{5}$$

b) <u>The decoupled gluon equation</u>. At high energies gluons dominate ($\bar{m}/\bar{n} \sim 2B/A$, $B \ll A$). Therefore, we can neglect quark evolution ($m = m_o = $ const). The evolution equation for the probability distribution P(n,t) is

$$\frac{\partial P_n}{\partial n} = -AnP_n - BnP_n - \tilde{A}mP_n - CnP_n + A(n-1)P_{n-1}$$

$$+B(n+1)P_{n+1} + \tilde{A}mP_{n-1} + C(n-2)P_{n-2} \quad , \tag{6}$$

This equation can not be solved exactly. We can make the same approximation as we did for the coupled quark-gluon equation and obtain the differential equation for the probability distribution $P(n,t)$. We find the following solution

$$P(n,t) = \int_0^\infty d\lambda w(\lambda) e^{-\lambda t} \psi(a,c,y) \tag{7}$$

where $\psi(a,c,y)$ is the confluent hypergeometrical functions regular for large y, $w(\lambda)$ is an unspecified weight function,

$$a = 1-\lambda/a_o \;, \; c = \frac{(a_1-\tilde{A}m)}{(a_1/2)} \;, \; y = \frac{a_o}{(a_1/2)}n, \quad a_1 = A+B+4C \quad . \tag{8}$$

For large y, $P(n,t)$ has a scaling and non-scaling piece. In the tail of the distribution non-scaling piece has a negative sign and scaling is approached from below as observed experimentally. We can solve Eq. (8) exactly if we neglect 4-gluon branching and assume n_o initial gluons. In the limit when we consider only gluons ($m=m_o=o$) and neglect $g\to ggg$, the probability distribution is the 3-gluon branching distribution[6)]

$$P_n^{n_o}(\bar{n}) = \frac{(n-n_o)!}{n!(n_o-1)!} \left(\frac{n_o}{\bar{n}}\right)^{n_o} \left(1-\frac{n_o}{\bar{n}}\right)^{n-n_o} \tag{9}$$

where n_o is the initial number of gluons. For large n and $\bar{n}$, it approaches the KNO scaling function:

$$\bar{n}P_n \xrightarrow[n,\bar{n}\text{ large}]{} \psi(z = \frac{n}{\bar{n}}) \simeq \frac{n_o^{n_o}}{(n_o-1)!} e^{-n_o z} z^{n_o-1} \quad . \tag{10}$$

All correction terms have negative signs indicating the approach from below to this scaling form, in agreement with data.

Finally, we consider the case when there are m_o initial quarks and no gluons. Neglecting 4-gluon branching and $q\bar{q}$ pair production we can solve Eq. (6) exactly. The solution is the negative binomial distribution

$$p_n^k(\bar{n}) = \frac{(n+k-1)!}{n!(k-1)!} \left(\frac{k}{\bar{n}}\right)^k \left(1 + \frac{k}{\bar{n}}\right)^{-n-k} \quad . \tag{11}$$

where

$$k = \frac{\tilde{A}m_o}{A} \quad \text{and} \quad \bar{n} = k(e^{At} - 1) \tag{12}$$

Since in the leading logarithm approximation $\tilde{A}/A$ is a constant, the only possible energy dependence of the parameter k can come from the energy dependence of the initial number of quarks m_o.

The UA5 group used this distribution to fit experimental data remarkable well from 10 GeV up to 900 GeV with k decreasing from 20 to 3.[8] However, this behavior for k does not fit into our physical picture. We note that in the large n and $\bar{n}$ _____ the negative binomial distribution approaches the same KNO scaling function [(Eq.(10)] as the 3-gluon branching distribution. However, for fixed k, the correction terms have positive signs indicating the approach from above in contradiction with the experimental data.

We conclude that in the parton branching model with coupled quarks and gluons there is no KNO scaling in the lowest approximation. At high energies when we neglect quark evolution, the probability distribution approaches scaling from below in the high z tail in agreement with data. The negative binomial distribution can be obtained in the branching model in the case of a quark jet, but it does not fit the experimental data.

The recent discoveries of the UA1 group[9] that "jet" events have a much narrower distribution and different mean multiplicity

($\bar{n}_{jet} \sim 2\bar{n}_{non-jet}$) than "no jet" events are offering a real challenge to many models. The shape of the distribution is also very sensitive to different cuts in the fractional momenta, different rapidity regions, distinction between the diffractive and nondiffractive events and the separation of the leading particles.[10] All this shows the importance of investigating the initial conditions in the parton branching model. Furthermore, one has to keep in mind that our model is applicable for non-diffractive events in the region where $p_\perp > p_\perp$ min and x not too near 1 and it does not include soft gluons.

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